UNIVERSAL WIRELESS EVENT MONITORING SYSTEM

A Thesis

by

LAMYANBA YAMBEM

Submitted to the Office of Graduate Studies of
Texas A&M University
in partial fulfillment of the requirements for the degree of

MASTER OF SCIENCE

May 2009

Major Subject: Electrical Engineering

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Approved by:

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ABSTRACT

Universal Wireless Event Monitoring System. (May 2009)

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Chair of Advisory Committee: Dr. Jun Zou

In an attempt to provide a more secure and amiable living environment in our homes, there has been constant effort to develop more efficient and suitable intelligent sensor technology for household application. Wireless sensors provide an efficient means of sensing without the need for messy wiring, and are ideally suited for the household environment. Although many sensor products have been developed (e.g. temperature, humidity and smoke), automated detection and reporting of an incidence occurring in places hard to observe or reach, such as wetting of diapers or water seepage under carpets, are still not readily available at low cost. Most of the existing technologies consist of complex design architecture and follow specific communication protocols which can be overkill for many simple household applications.

In this thesis, we present a new wireless sensor system which is based on the detection of just the ON or OFF state of a condition. This approach overcomes the need for complex architecture and design, but is still able to achieve the functionality that is required for many household applications such as water leakage, food rotting, diaper wetting etc. and thus can be made available very cheaply.

The sensor system consisting of an interrogator and a sensor circuit is implemented using inductive coupling. A passive L-C circuit is used for the sensor design and the system is tested using diaper wetting as an example of a simple household application. The testing results shows that the sensor can detect an ON and OFF condition for sensor and tag separation of 10 cm which is enough for applications like water leakage behind walls and under carpets, diaper wetting, food rotting etc.

DEDICATION

To my Parents, Tarana, Tutu and Kaju

ACKNOWLEDGEMENTS

I would like to thank my committee chair, Dr. Jun Zou, and my committee members, Dr. Cheng, Dr. Karsilayan and Dr. Song, for their guidance and support throughout the course of this research. I would also like to thank Murat and Karthik for their help in circuit testing and fabrication phase of the project.

I would also like to extend my gratitude to my friends and colleagues and the department faculty and staff for making my time at Texas A&M University a great experience.

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CHAPTER I

INTRODUCTION

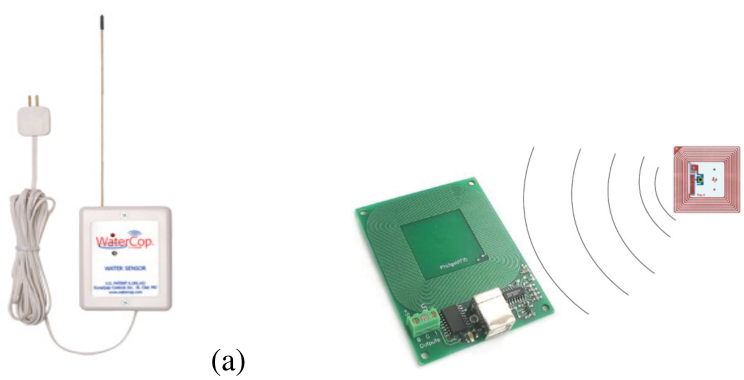
As sensor technology develops there is an increasing interest and need to develop smart sensor technology for household applications . Intelligent sensor systems play an important role in making our household a safe and amiable living environment. Sensors can be integrated with our home environment (as shown in fig.1) and be used to monitor a number of parameters such as temperature, humidity, gas, water and give us warning about any changes or events that might be a threat to our day to day life. Of the different

Fig.1 Integration of sensor systems for home monitoring ((A) Sensors placed around the house, (B) Central monitoring system and (C) A case of emergency detected by a sensor) [1]

This thesis follows the style and format of *IEEE Sensors Journal.*

sensing approaches that are available, wireless sensors overcome the need for direct contact and are ideally suited for the home environment as the wireless feature eliminates all the messy wiring schemes that are needed for other approaches.

A number of remote query sensor systems have been investigated and various products have been developed for sensing different applications like water leakage, temperature, pressure, gas, diaper wetting etc [2-7]. The wireless link in these systems which is needed between the sensor itself and the central monitoring system can be achieved through a various approaches. Many available products use RF transmission where active battery powered sensors are deployed in the locations of interests to monitor the area, and sends a signal back to a main station to indicate the condition at the location [6-7]. The use of battery powering the sensor however makes it limited to power supply in addition to it being a bigger in size. Another approach that have been



(a) (b)

Fig.2 Types of wireless sensors (a) Active sensor device [7] (b) Passive sensor device with transmitter/reader [8] reported by K. Opasjumruskit, T. Thanthipwan, O. Sathusen, P. Sirinamarattana, P. Gadmanee et al. is the modification Radio Frequency Identification (RFID) technology, which is normally used for data transmission, to implement sensor function for monitoring temperature wirelessly [3]. Here the RFID tag is modified in such a way that the temperature sensing chip is integrated in the circuit and the readings are communicated wirelessly through the reader as in normal RFID operation for data communication. RFID Reader and Tag system have also been modified in number of different ways to enable sensor functionality [8-9]. One of the means of remote query sensing is the direct measurement of impedance of antenna which is wirelessly connected to the sensor. By measuring the impedance of the antenna using instrument like Impedance analyzer or network analyzer, the exact degree at which the sensor is experiencing a condition can be monitored [5].

(a) (b)

Fig.3 Possible sensors applications (a) Water leakage behind walls (b) Diaper Wetting [10]

However, use of approach like battery powered active sensor device, RFID Reader Tag system etc. makes the system or the sensor itself more complex, and thus expensive. For many simple household applications like water leakage, food rotting, diaper wetting etc, these systems can be an overkill of the solution.

For many simple applications (fig. 3), a low-end wireless sensor system which overcomes the need for large data transfer and specific communications protocols will reduce the complexity of the design architecture and make products easily available at much lower cost. In this thesis we look for a new approach to wireless sensing which will only look for two predetermined condition (“ON” or “OFF”) of the sensor under different application scenarios and thus, overcomes the need for accurate measurement of sensor condition and can be implemented very easily. This can be achieved with cheap passive sensor placed in specific locations of interests and an external Interrogator system which communicates wirelessly with it and determine the sensor’s condition.

Scope and Structure of the Thesis

The universal wireless event monitoring system presented in this thesis consists of an interrogator unit and a sensor device. The sensors are placed in a specific location of interest where a parameter needs to be monitored and detects only the ON and OFF state of the condition (like wet Diaper (ON) or dry Diaper (OFF)). The transmitter connects wirelessly to the sensor and any change in the ON or OFF condition of the sensor is detected wirelessly.

This document is organized as follows: In Chapter II, the different techniques to communicate with sensors without the need for wires or use of battery in the sensors is discussed. Chapter III presents the system design and configuration and chapters IV presents the sensor design. Chapter V describes the testing and results obtained using the circuits described in Chapter III and IV. The document ends with Chapter VI, Conclusions and includes a reference section of work that has been used in development of this research.

CHAPTER II

RF SENSING SCHEME

RF Wireless Transmission for Passive Sensors

One of the main aspects of the research was to find a feasible wireless communication scheme which can be used to communicate with passive sensors and can be implemented easily without the need for complex design architecture. The two main available approaches to achieve wireless sensing for passive sensors are:

i) RF Backscattering

ii) RF Inductive Coupling

RF Backscattering: In this approach the systems usually consist of a reader/interrogator and a sensor. The reader transmits an RF signal from its antenna to the sensor. The sensor uses this RF signal to power its circuit and then sends a signal

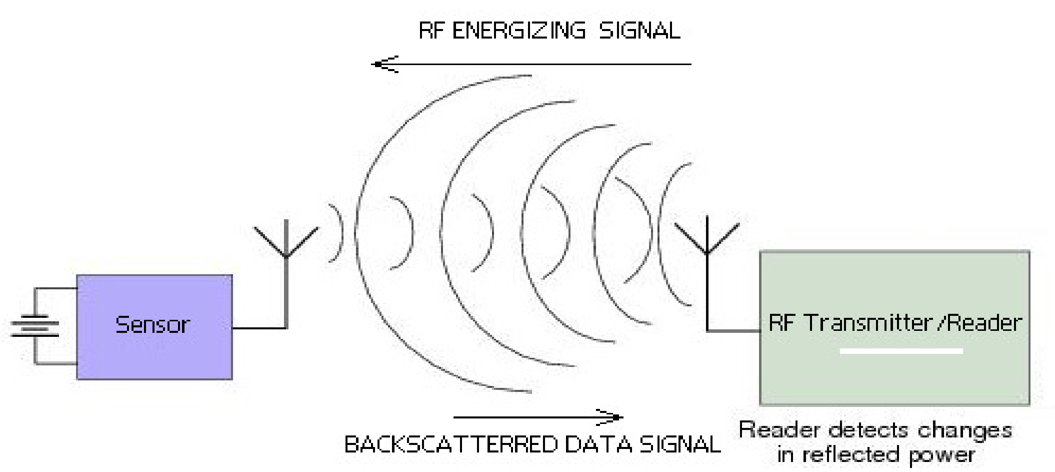


Fig.4 RF backscattering communication with passive sensor

back to the Reader (fig. 4). The reader can thus read the condition prevailing at the sensor's location by interpreting the signal from the sensor [8-9].

Use of RF backscattering for sensing by determining the impedance of the sensor through the backscattered signal has also been reported [11]. The main advantage of this approach is that it has a relatively longer range of operation, and can have functionality like communicating with multiple sensors. However the sensor circuit needs to be able to harness the RF energy and transmit back information about the sensor condition to the interrogator, and thus have more complex circuit.

RF Inductive Coupling: In this approach the sensor is communicated from the interrogator through inductive coupling [12-16]. The sensor is connected to the

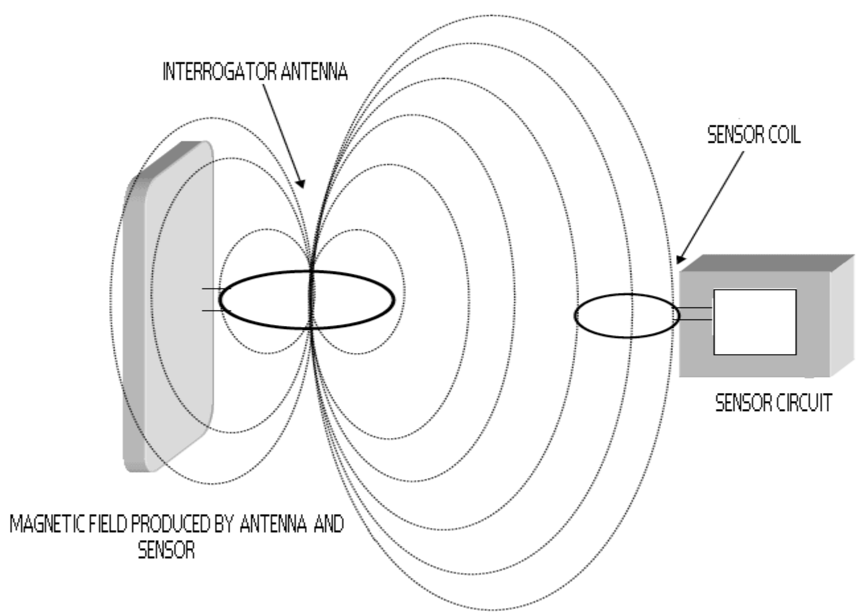


Fig.5 RF inductive coupling between the interrogator and the sensor

interrogator as a load of the interrogator through inductive coupling (fig. 5). The sensor impedance which changes according to the condition of the application is reflected on the interrogator as a change in load, and thus the application can be monitored by determining the interrogator load change.

The range for this system is reduced when compared to the RF backscattering as Inductive coupling is a near field phenomenon and have limitations in extending the range. The main advantage however is that the sensor circuit becomes much simpler and can be implemented with only a simple L-C circuit.

In this thesis, we look into the approach of Inductive coupling to achieve passive wireless sensing as it simplifies the sensor circuit, and makes the product easier to implement and thus cheaper.

Inductive Link (Theory and Implementation)

The inductive link used to couple the sensor and the transmitter is established between the transmitter antenna and the sensor inductance. A magnetic coupling between the two coils makes them behave like a loosely coupled coreless transformer. A

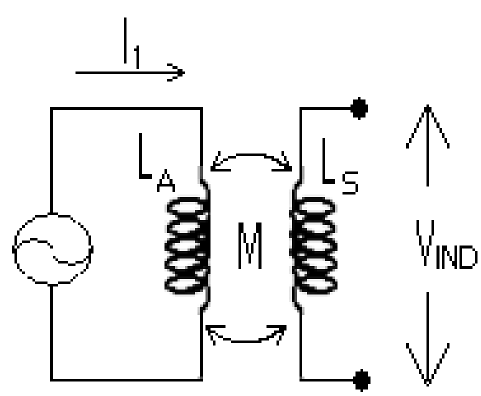


Fig.6 Inductive coupling between two coils

sinusoidal current generator in the interrogator generates an RF current in the antenna coil L_A which induces a current in the inductor coil of the sensor. If we assume that the sensor circuit is open as shown in fig. 6, then we can think of the voltage induced on the sensor circuit as V_{IND}. The relationship between the induced voltage on the sensor circuit and the current I_1 in the antenna coil (L_A) is given by:

$$V_{IND} = M * (dI_1/dt) \qquad (1)$$

M in the above equation is the Mutual Inductance between the two coils. This induced voltage in the sensor circuit generates the sensor current. If we have a sensor current I_2 induced in the sensor circuit due to inductive coupling between the sensor inductor coil and the antenna coil as shown in fig. 7, then the relationship between the current in the interrogator (i_1) and the sensor (i_2) can be derived.

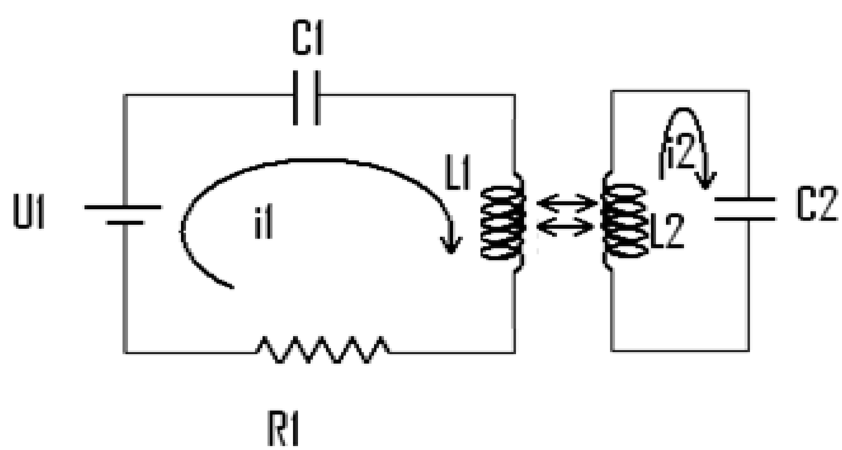


Fig.7 Induced current in sensor circuit through inductive coupling

If R_2, L_2 and C_2 represent the resistance, Inductance and Capacitance respectively in the sensor circuit, then the induced current can i_2 can be given as

$$j\omega M i_1 = j\omega L_2 + R_2 i_2 + i_2/j\omega C_2 \qquad (2)$$

Where the RHS represents the voltage induced in the sensor circuit.

The current voltage relationship in the Interrogator circuit can be represented by:

$$U_1 = R_1 i_1 + j\omega L_1 i_1 + i_1/j\omega C_1 - j\omega M i_2 \qquad (3)$$

Here, U_1 represents the voltage source, and R_1, L_1 and C_1 represents the total resistance, inductance and capacitance in the interrogator circuit respectively. The impedance of the sensor as seen from the interrogator circuit through the inductive coupling can be written as:

$$Z_S = \omega^2 M^2/(j\omega L_2 + R_2 + (j\omega C_2)^{-1}) \qquad (4)$$

The current flowing in the Interrogator circuit can thus represented in the form

$$i_1 = U_1 /(Z_I + Z_S) \qquad (5)$$

Where Z_I represents the total internal impedance of the interrogator circuit and Z_S represents the impedance produced by the sensor through the Inductive coupling. Thus by making the impedance (either inductance or capacitance or both) change according to sensing application, this sensor system can be applied universally for a number of different applications.

As can be seen from the eqn. (4), mutual inductance (M) is one of the main factors that determine the sensor impedance (Z_S) reflected on the interrogator side. In order to maximize the effect of the sensor on the interrogator circuit, this factor needs to be maximized.

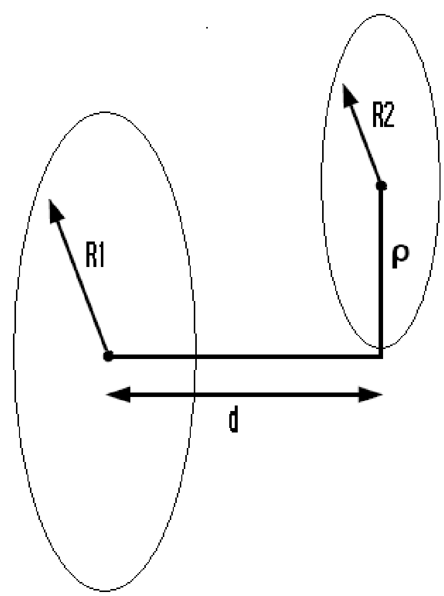


Fig. 8 Mutual inductance dependence on coil alignment and separation - d is the separation between the parallel face of the coils, R_1 and R_2 are the oil radii and ρ is the separation between two centers.

For two coils aligned parallel to each other (fig. 8), separated from each other by distance d and lateral misalignment ρ, with R_1 and R_2 as their radii, the mutual Inductance (M) can be derived according to [17] as

$$M_{12} = \mu_0\pi\sqrt{(R_1R_2)} \int J_1 (x\sqrt{(R_1/R_2)}\, J_1 (x\sqrt{(R_2/R_1)}\, J_0 (x * \rho / \sqrt{(R_1R_2)}).exp (- x * d / \sqrt{(R_1R_2)})\, dx \qquad (6)$$

Where J_0 and J_1 are zeroth and first order Bessel function respectively. When the coils are perfectly aligned to reduce the lateral distance ρ to zero, the equation simplifies to:

$$M = \mu_0\sqrt{(R_1R_2[((2/t) - t)\, k(t) - (2/t)\, E(t)]} \qquad (7)$$

Where $t = (\sqrt{(4R_1R_2)})/[(R_1 + R_2)^2 + d]^2$

And k(t) and E(t) are complete elliptical integral of first and second kind respectively.

Thus to maximize the mutual coupling between the two coils, they are aligned parallel to each other and the lateral displacement between them is minimized. The coils are placed in fixed position so that the only factor changing the inductive link is the one affected by the parameter which is being monitored.

CHAPTER III

SYSTEM DESIGN AND CONFIGURATION

System Configuration

As shown in fig.9 the whole sensor system consists of the Interrogator Unit and the Sensor Unit which communicate with each other through inductive coupling. The interrogator function as an active battery powered device which generates RF sinusoidal current through the antenna and produces a magnetic field around it. The sensor tag was designed as a passive L-C resonant circuit. The inductor coil couples with the antenna when it is placed in the field around the antenna.

The sensor is designed in such a way that the capacitor or the inductor value changes with any change in the condition that sensor is monitoring. This in turn changes the resonant frequency of the sensor and affects the inductive coupling between the sensor and the interrogator units which is detected as an event in the interrogator.

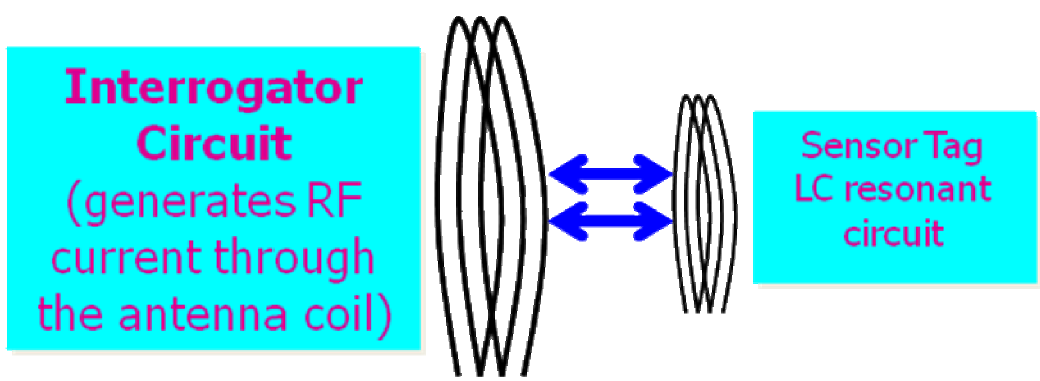


Fig. 9 Sensor system configuration

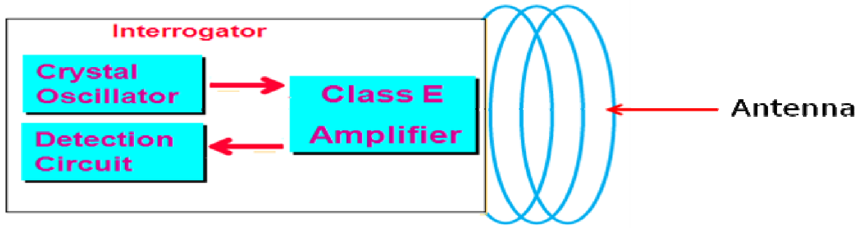


Fig. 10 Interrogator circuit configuration

Interrogator Design

The Interrogator unit consists of three main circuits, as shown in fig.10:

i) Crystal Oscillator

ii) Class E Amplifier and

iii) Detection Circuit.

The antenna function as an inductor for the Class E amplifier circuit and is fed the RF current which flows through the circuit. The Crystal Oscillator which consists of a quartz crystal circuit shown in fig. 11, generates a square wave signal of specific frequency. It provides a cheap and efficient way to generate a switching signal at the frequency of operation for class E amplifier which is required to generate RF current in the circuit.

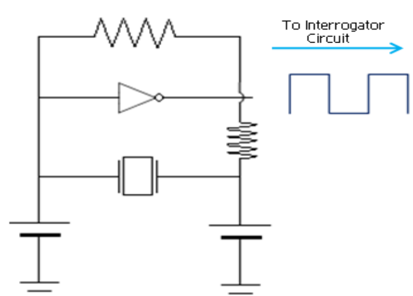


Fig.11 Crystal oscillator circuit

Class E Amplifier Design

The main requirement of this system is to find a way to generate sinusoidal waves through at the frequency of operation. As the Interrogator is a standalone battery powered device, it needs to be an effective DC to AC converter that can provide the AC current at the required frequency. Class E Amplifier was chosen for this project as it can achieve a very high efficiency and also provide amplification to generate higher voltage at the antenna coils that cannot be provided by the battery source.

The Class E Amplifier is a tuned power amplifier topology consisting of a single pole switches and load network which was invented by Nathan and Alan Sokal [18]. In most RF power amplifier the main power loss occurs at the power transistor, which is the product of the transistor voltage and current. Class E Amplifier achieves much lesser loss by operating in such a way that the voltage and the current do not overlap. The type of loading network used in this topology (Shown in fig.12) is called the multi-frequency load network. In this network, L and C_2 have a resonant frequency of f_2 and the combination of L, C_2 and C_1 also have a resonant frequency which is higher than f_1.

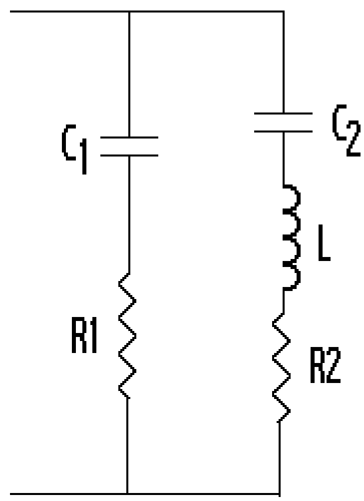


Fig. 12 Multi-frequency load network used in Class E Amplifier

When the operating frequency of the network lies between f_1 and f_2, there exists a point at which the voltage and the current waveforms are 180^0 out of phase of each other and efficiency of the network is maximized [19-20]. This point has the maximum switch voltage accompanied by the minimum (ideally zero) switch current, and vice versa, and exhibits a minimum loss of power at the switch.

A simple implementation of this network configured as a Class E Amplifier is shown in fig.13. The NMOS act as a switch which closes and open according to the switching signal provided at its gate. When the switch is closed, the all the current flow through the switch and the capacitor C1 has no charging current flowing through it and the voltage across the switch is zero [12-20].

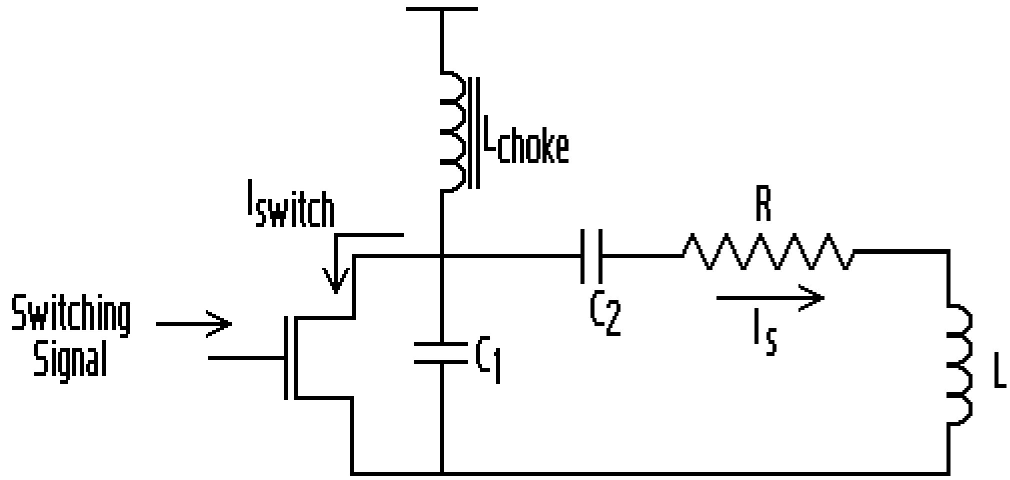


Fig. 13 Schematic of Class E Amplifier technology

The current over the switch I_{switch} is supplied by the L and C_2. When the switch opens up, the L and C_2 continues to supply current but the current now flows through C_1 and starts charging it, increasing the voltage across the switch. When the current reverses direction, C_1 act as the source and current starts flowing from it until it is completely discharged. At this point, when the voltage across the switch is zero, the switch is again closed and current start flowing through it. The whole process is then repeated again. For sufficiently high quality factor, the L-C_1 branch of the amplifier can be assumed to be nearly sinusoidal with a frequency equal to the switching frequency received at the switch. The circuit gives out minimum power dissipation when the frequency of operation is at a particular frequency (Class E frequency) between these two frequencies determined by the values of C_1, C_2 and L. The amplifier can be design by taking this frequency of operation as the central frequency and designing the values of the components around this frequency.

To determine the component values of the Class E Amplifier circuit, the frequency of operation is first chosen. For this application, a frequency of 12MHz was chosen to be the operating frequency as it would give a high magnetic coupling and would still be able to overcome the complexity required in designing circuit when the frequency goes higher. To further determine the component values of the circuit, we need to have a specific quality factor, duty cycle of the switching signal. To be able to achieve sinusoidal current on the circuit at the frequency of the switching signal, a high quality factor of 10 was chosen for this circuit. A duty cycle of .5 was chosen for the switch as this corresponds to the minimum power loss in the circuit. The antenna which gives the inductance L of the circuit was first designed to determine its Inductance value, and then the other components were calculated by using the other designed parameters that was chosen before.

In order to maximize the inductive coupling effect from the Antenna, a spiral loop antenna was chosen as the antenna for this application [21, 22]. An initial design using rectangular spiral loops was implanted on a Printed Circuit Board (PCB) to function as the antenna. The number of loops and the spacing between the antenna coils was determined by simulating the turns on Sonnet®. The rectangular printed antenna in fig.14 was fabricated on a $(60*30)mm^2$ and had 0.5mm spacing between the turns, achieved an Inductance(L) of 2.4μH.

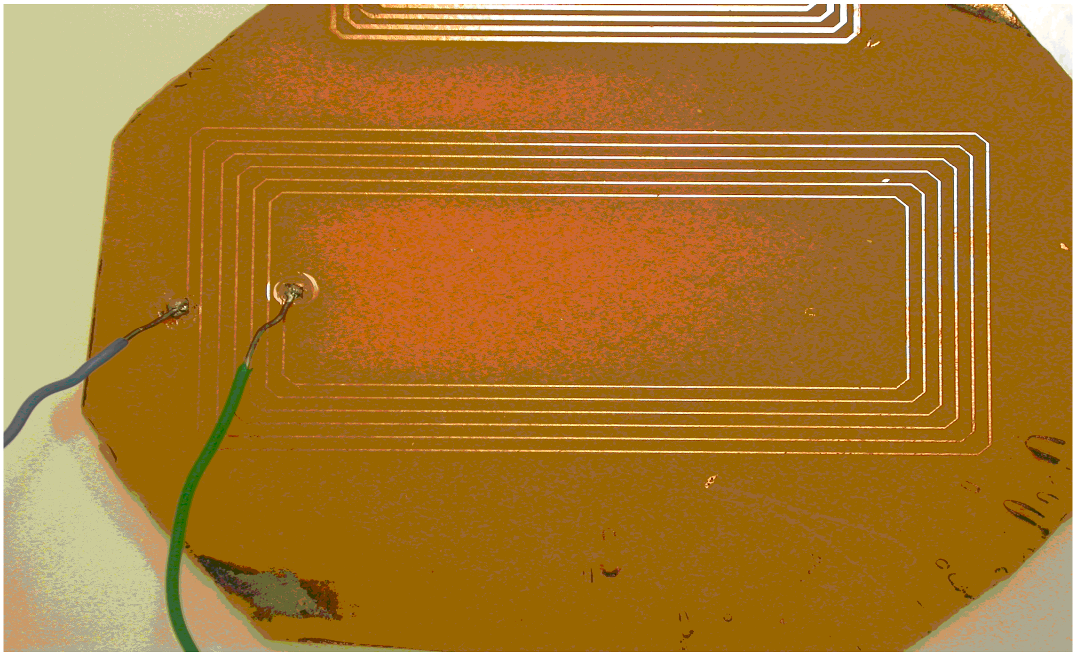


Fig.14 Printed circuit rectangular spiral antenna

A second circular coil antenna made from wires, which was bigger in diameter, was also designed as the initial implementation of the circuit using the Printed antenna had a very small range of operation. The wire antenna shown in fig.15 had an external diameter of 12cms, and the four circular spirals had a separation of 0.5 cm. The Inductance achieved was 3.1μH.

For the final testing and implementation of the circuit, the circular wire antenna was used. The Inductance (L) of 3.1μH was used as the first component value and all other components were determined from it using the Class E amplifier design procedure.

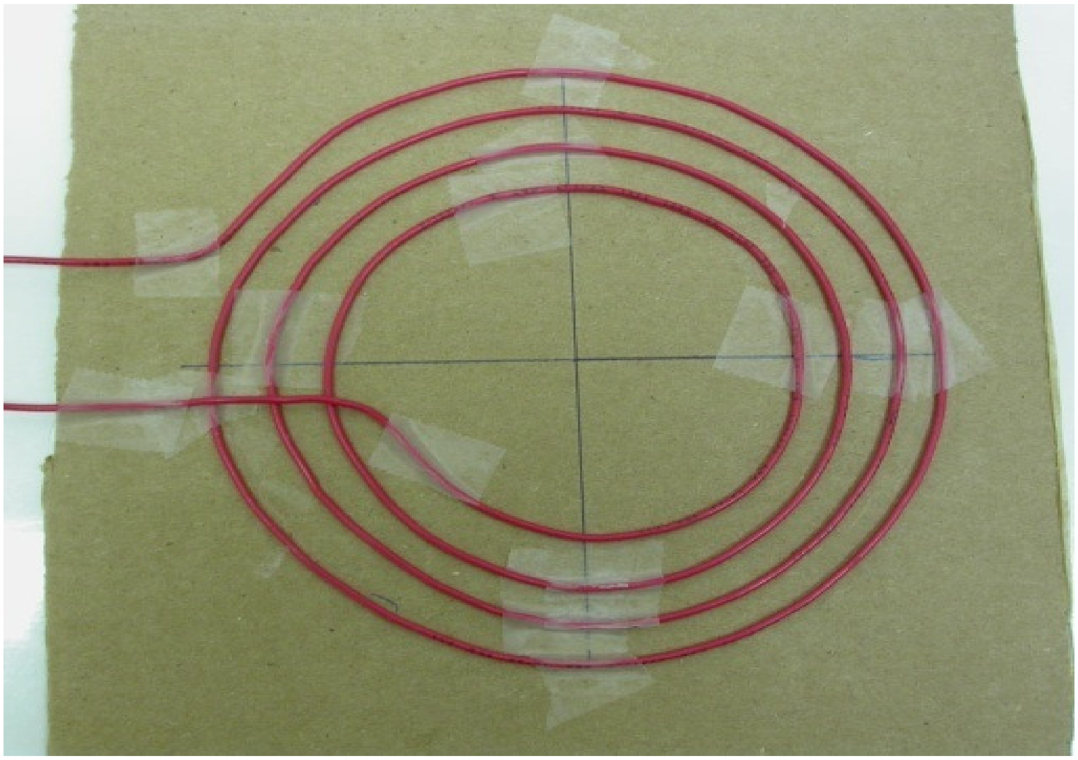


Fig.15 Circular spiral wire antenna

A definite design procedure actually does not exist for class E amplifier circuit. The solution is to either solve the exact differential equation using the design parameters or to make assumptions which would make the solution easier to arrive. A series of design equation for low-order lumped element class E circuit with the switch duty cycle of .5 is given by Sokal in [18] and [23]. Kazimierczuk has provided another approach to find the component values in which he gives a table to determine the relationship between the operating frequency and the other two boundary frequency using the Quality factor and the Switch Duty cycle [20]. This approach is adapted to calculate all the component values needed for the Class E amplifier.

In the circuit given in fig.3.5, when the switch is closed, the current flows through only the L-C_2 branch of the circuit. The quality factor and the resonant frequency of this state are given by:

$$\omega_1 = 1/\sqrt{(L*C_2)} \qquad (8)$$

$$Q_1 = \omega_1 L/R = 1/(\omega_1 R C_1) \qquad (9)$$

When the switch opens, the current starts flowing through L-C_2-C_1 and changes the resonant frequency and the quality factor of the circuit. The new values are given by:

$$\omega_2 = 1/\sqrt{[(LC_1C_2)/(C_1+C_2)]} \qquad (10)$$

$$Q_2 = \omega_2 L/R = \omega_2 R(C_2C_1)/(C_1+C_2) \qquad (11)$$

The ratio of the switching frequency (operating frequency) can be given as:

$$A_1 = \omega_1/\omega_0 = f_1/f_0 \qquad (12)$$

$$A_2 = \omega_2/\omega_0 = f_2/f_0 \qquad (13)$$

The quality factor of the circuit when the circuit is operating at the Class E frequency can be determined by the equation:

$$Q_l = \omega L/R = Q_1/A_1 = Q_2/A_2 \tag{14}$$

Using a set of equations which relates the A_1, A_2, Q_1, Q_2, a look up table was created by Kazimeirczuk [20]. The lookup table is given in Table. 1.

Table.1 Look up table for calculating component values for Class E operation [20]

Q_1, Q_L, A_1, AND A_2 AS FUNCTIONS OF Q_1 AND D

Q_1	D											
	0.25				0.5				0.75			
	Q_2	Q_L	A_1	A_2	Q_2	Q_L	A_1	A_2	Q_2	Q_L	A_1	A_2
0	4.965	4.445	0	1.117	2.866	1.788	0	1.603	2.612	0.821	0	3.182
1	5.141	4.619	0.2165	1.113	3.247	2.104	0.4752	1.543	3.715	1.247	0.8018	2.979
2	5.616	5.093	0.3927	1.103	4.124	2.850	0.7018	1.447	6.017	2.161	0.9256	2.785
3	6.292	5.765	0.5204	1.091	5.146	3.750	0.8001	1.372	8.302	3.157	0.9502	2.630
5	7.946	7.413	0.6745	1.072	7.242	5.673	0.8814	1.277	12.345	5.171	0.9670	2.387
7	9.777	9.239	0.7577	1.058	9.321	7.642	0.9160	1.220	15.877	7.182	0.9747	2.211
10	12.645	12.102	0.8263	1.045	12.405	10.621	0.9416	1.168	20.699	10.192	0.9812	2.021
15	17.576	16.994	0.8826	1.032	17.488	15.605	0.9612	1.121	27.590	15.201	0.9868	1.815
20	22.492	21.940	0.9116	1.025	22.536	20.597	0.9710	1.094	33.969	20.207	0.9898	1.681
100	102.37	101.81	0.9822	1.006	102.68	100.58	0.9942	1.021	119.78	100.22	0.9978	1.195
∞	∞	∞	1	1	∞	∞	1	1	∞	∞	1	1

Once Q_L is known using the table above, for the chosen circuit, component values for C_1 and C_2 can be determined using the following equations:

$$C_1 = 1/(\omega_0 R Q_L(A_1^2 - A_2^2) \quad (15)$$

$$C_2 = 1/(\omega R Q_L A_1^2) \quad (16)$$

The equations used in the design procedure assumed a number of ideal situations, like a perfect choke coil which act as an ideal current source, an ideal zero turn on resistance. To attain near ideal 180^0 phase difference between the current and the voltage waveform at the switch after determining the component values with the ideal condition assumption, a tuning procedure is provided by Sokal in [23]. The procedure in fig.16 gives a method to tune the circuit operation using C_1 and C_2, once the other values are fixed.

The component values were first calculated using the design equations, and then tested on the circuit board. The component values of the circuit were then experimentally changed using the suggested method given in fig. 16 to achieve optimum performance. Table 2 below gives the list of the values calculated from the equations along with the final values used after the tuning the circuit.

Table. 2 Calculated and final values for the Class E amplifier circuit components

Name	Calculated	Final Value
Capacitor C_1	32pF	8.3pF
Capacitor C_2	110pF	60pF
Resistance R	5.7ohms	11ohms
Choke Coil	>164uH	300uH
Inductance L	3.2uH	3.2uH

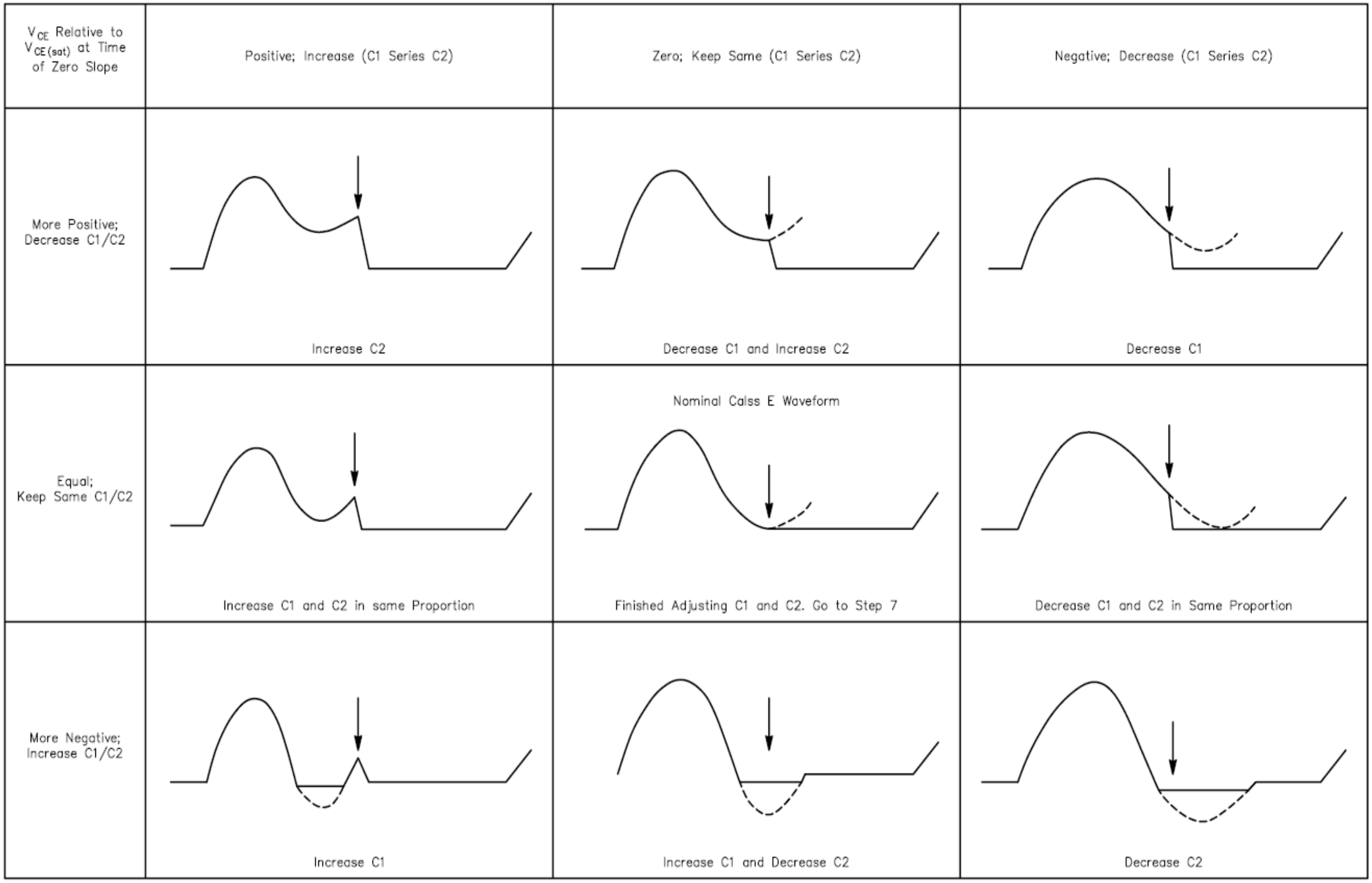


Fig.16. Circuit tuning using C_1 and C_2 [23]

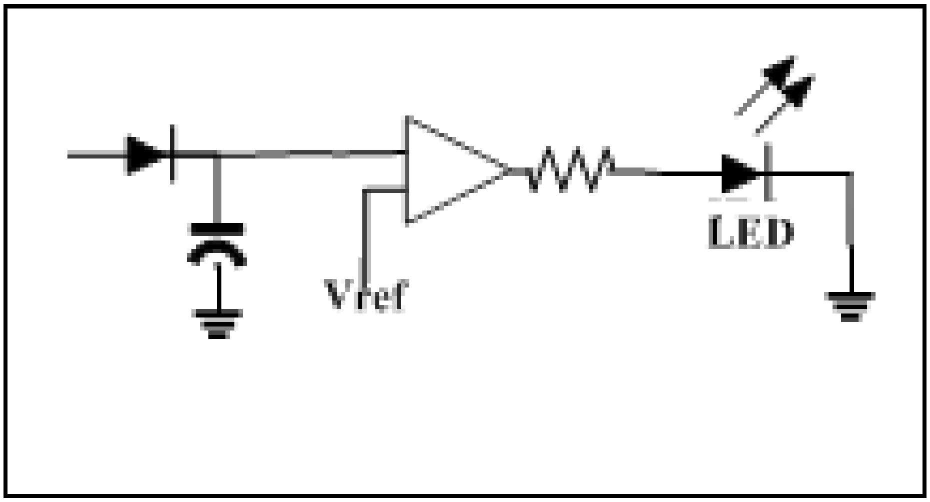


Fig.17 Detection circuit

Detection Circuit

The main function of the detection unit is to detect any change in the current flowing through the Interrogator, by detecting the change in voltage that is inputted to it. It consists of three parts rectifier circuit, a comparator and an LED as shown in fig.17.

The rectifier converts the AC Voltage experienced by it from the circuit into DC voltage. This DC voltage level which is a reflection of the current flowing in the circuit is fed into the comparator. The comparator has one of its inputs set to the reference voltage (V_{ref}). The reference voltage is a stable voltage just below the interrogator DC voltage level, and the difference between the two defines a threshold voltage which the sensor needs to affect the Interrogator circuit working through the inductive link between the two to have an event triggered as an ON/OFF event. The reference voltage can be set to a particular voltage depending on the application. When the voltage on the comparator goes above the reference voltage set on the comparator, the comparator output voltage goes high.

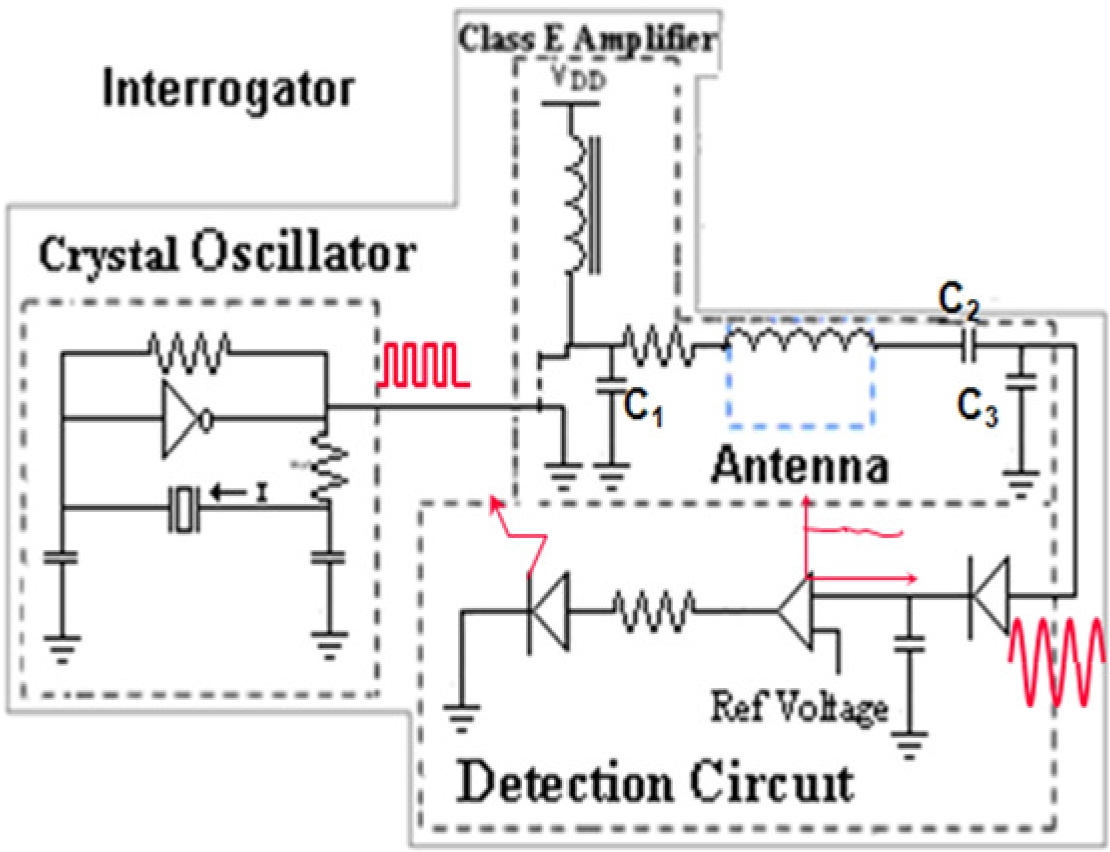


Fig.18 Complete interrogator circuit in operation

The complete Interrogator circuit is shown in fig.18. The crystal oscillator provides a switching square wave signal with 50% duty cycle to the gate of the MOSFET of the Class E amplifier. The MOSFET which act as a switch is opened and closed by the switching signal, thus charging and discharging the capacitor C_1, and generating a sinusoidal current and voltage in the circuit. The frequency of operation which is 12MHz is defined by the crystal oscillator through its switching frequency, and the class e amplifier by virtue of its high quality factor and component values also follows. The capacitors C_2 and C_3 form a capacitive voltage divider and control the voltage fed in the rectifier so that only a fraction of the actual interrogator voltage (which can be very high) is fed in the detector circuit. The detector circuit takes the AC voltage from the capacitive voltage divider and converts it into DC voltage.

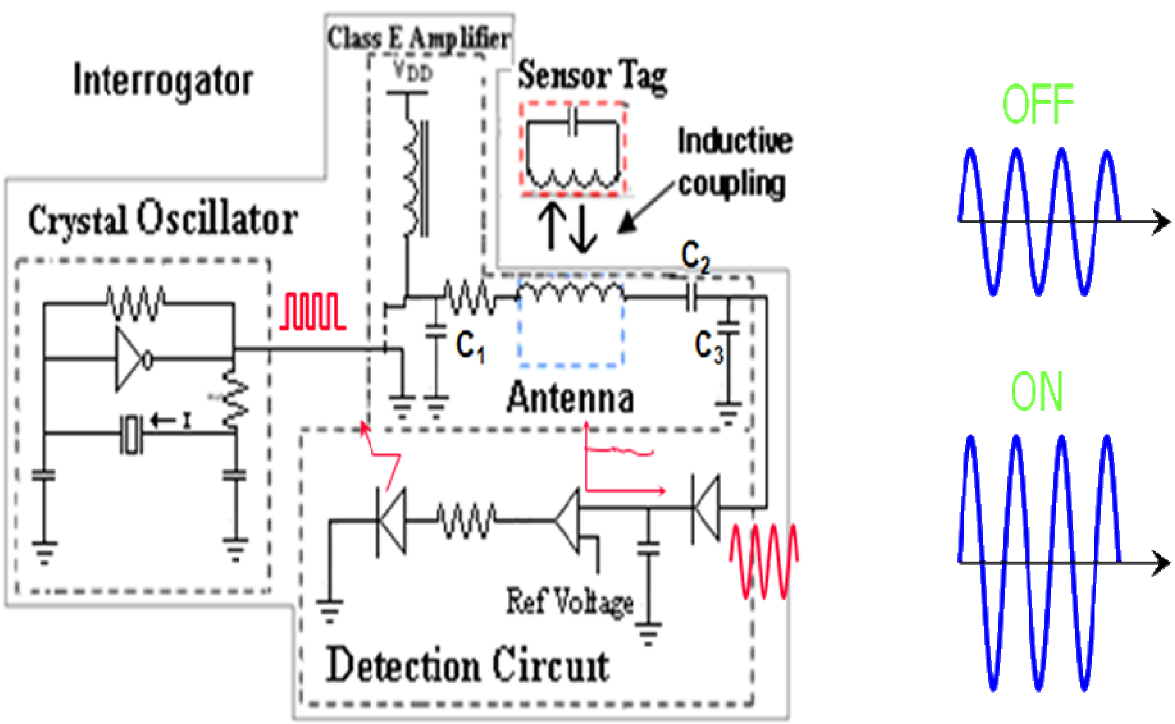


Fig.19 Sensor system analysis

Thus when the Interrogator is started and a sinusoidal current runs through the antenna, it couples inductively with the sensor tag. The sensor tag thus acts as a source of Impedance through the link and affects the Interrogator circuit. This can be indicated as the OFF voltage condition as indicated in fig 19. When the sensor is experiences a condition that changes the sensor Inductance or capacitance, and thus changes its resonant frequency, the inductive link is reduced. This gives a rise in voltage as the sensor Interrogator voltage which can be referred to as Sensor ON voltage as shown in fig. 19. The Detector circuit which converts the AC voltage to DC and compares with the reference voltage reads this rise from OFF to ON voltage as a sensor event and lights up the LED to indicate the event.

CHAPTER IV

SENSOR DESIGN

The sensor tag is designed as a passive Inductor (L) – Capacitor (C) resonant circuit as shown in fig.20. The sensor resonant frequency is designed to have the same value as that of the Interrogator frequency of operation to maximize the Inductive coupling between the two. The sensor is thus designed using the simple resonant frequency equation and making it equal to the Interrogator operation frequency.

$$f = 1/\sqrt{(L*C)} \tag{17}$$

The size for the sensor tag was decided to be 5*5 cm^2 to make it portable and easily placed.

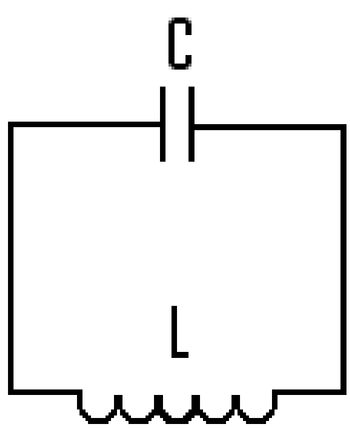


Fig.20 Passive LC sensor tag circuit

Using this size as the base, the sensor tag was designed as a rectangular spiral coils which makes up the inductor connected to a parallel plate capacitor. The coil design was first simulated in sonnet for number of coil turns and spacing, and the inductance and the capacitance values were decided according to the optimum inductance that can be obtained in the set sensor tag area.

The sensor was fabricated on a Printed Circuit Board and then tested [24]. The final fabricated tag is shown in fig.21 it has a coil width of 2mm and a spacing of 2mm between the coils. The parallel plate area of the sensor tag was 2*2 cm^2. The Inductance of the resulting coil is 3.8μH and the Capacitance of the parallel plate capacitor is 46.3 pF.

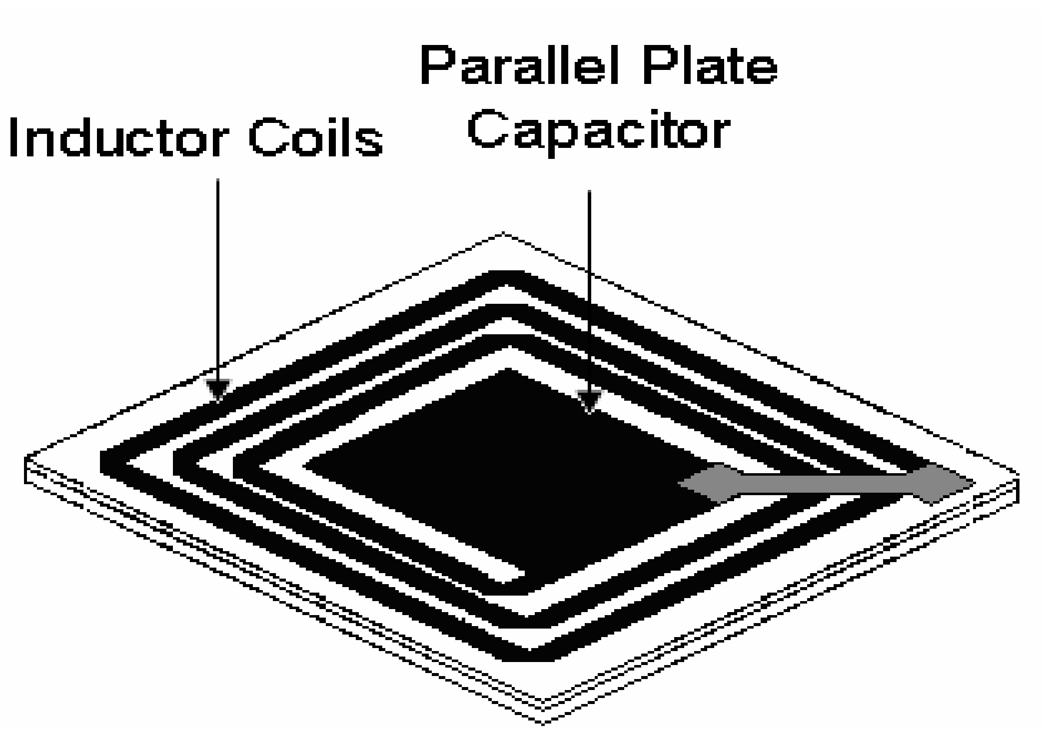


Fig.21 Sensor tag

CHAPTER V

IMPLEMENTATION AND TESTING

To test the Universal event monitoring system, detection of diaper wetting is chosen as an example of simple household application that the system can be used to monitor. The testing set-up for the experiment is shown in fig.22.

The testing set up for the experiment is done with the following testing specs:

- DC supply: 9V battery
- Resonant frequency: 12MHz.
- Antenna: 12cm diameter, L=3.1μH
- Class E amplifier: C_1=8.3pF, C_2=60pF, C_3=300pF.
- Sensor tag: 5×5cm^2, L=3.8μH and C=46.3pF.
- MOSFET Switch – IRF510 [25]
- Comparator – AD8561 High speed precision comparator [26]

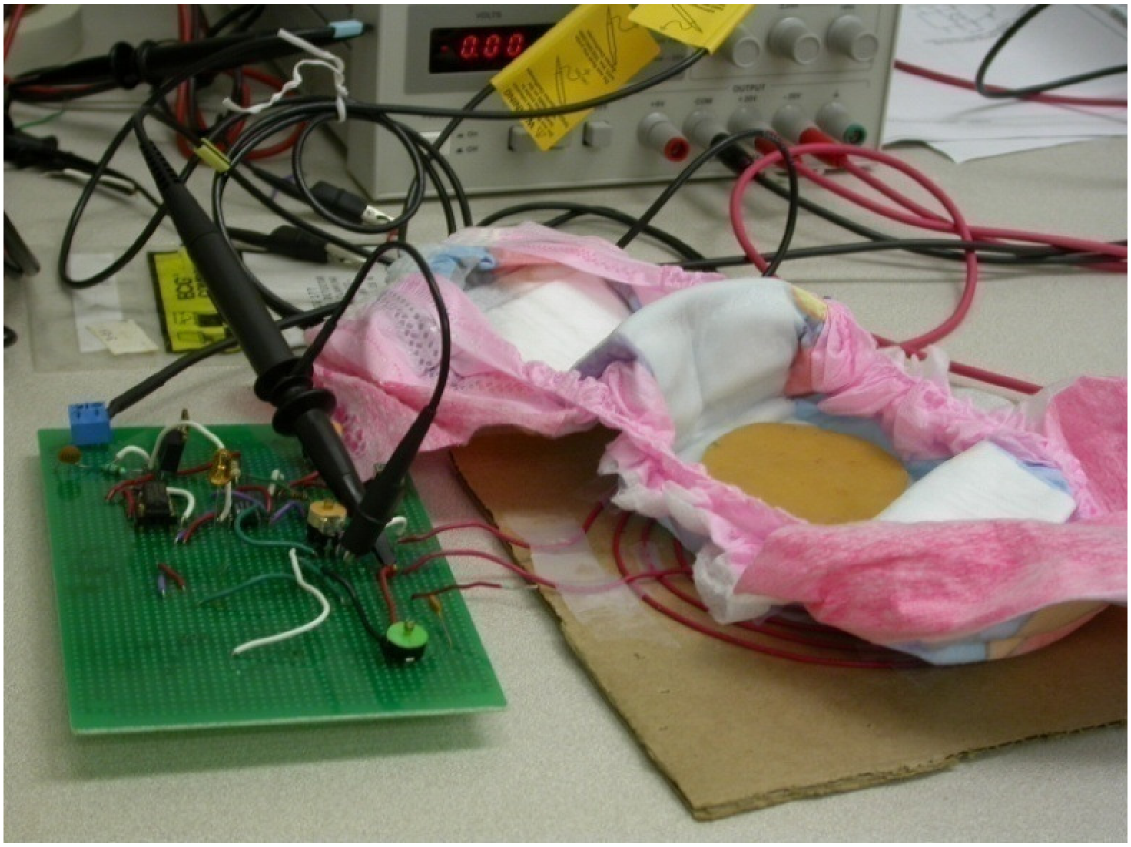


Fig.22 Testing set up for using the sensor to monitor diaper wetting

The testing was done with the sensor tag placed inside a diaper soaked in saline solution to simulate baby wetting of diapers. The sensor tag with the diaper is then placed in the range of the Interrogator antenna and readings were taken for two different condition of the diaper – dry (OFF) and wet (ON). The testing results which show the waveform of the AC voltage level of the Interrogator and the DC voltage level given to the comparator is shown in fig. 23.

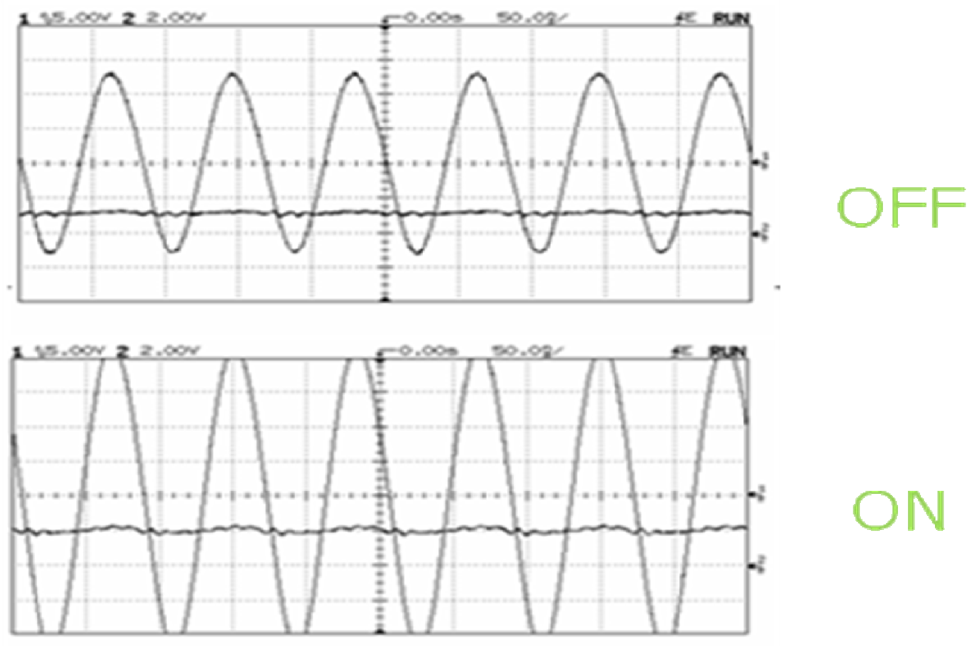


Fig.23 Interrogator voltage waveforms for ON and OFF condition of the sensor

When the diaper gets wet by the saline solution, the sensor circuit gets shorted and the effective impedance of the sensor which is reflected on the interrogator circuit through the inductive link is reduced to zero. This causes the voltage level in the Interrogator circuit to rise. This difference in the voltage level of the two condition (shown in fig.21) can is thus detected by the detector circuit as an ON event which lights up the LED.

The shift in the voltage between the ON and OFF condition was also tested for different separation between the Interrogator antenna and the sensor tag in order to find out the operating range of the sensor system. Fig. 24 shows the voltage shift value for different sensor – antenna separation. As can be seen, a voltage shift of ~250mV can be seen for a separation of 10 cm which enough for many simple household applications is like diaper wettings, water leakage behind walls and under carpets etc.

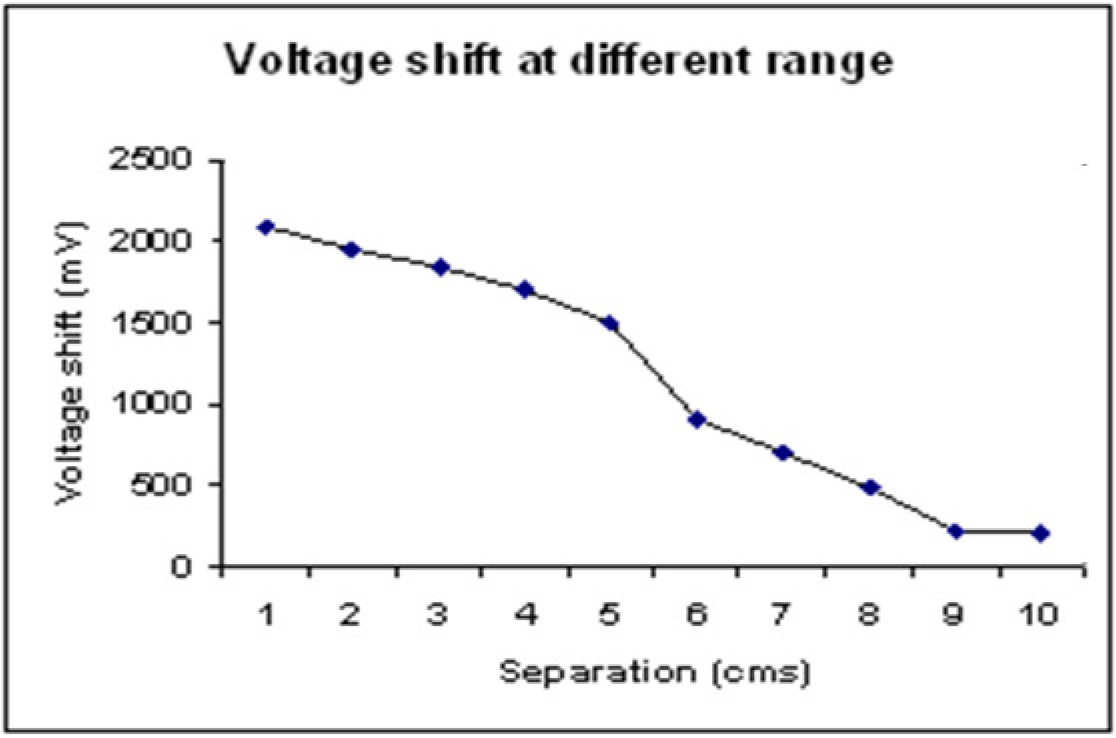


Fig. 24 Shift in voltage for different separation between the sensor and the antenna

CHAPTER VI

CONCLUSION

In conclusion, we presented a new approach to wireless sensing based on recognition of only two states of the sensor system (‘ON’ and ‘OFF’) which can achieve sensing functionality for a number of household applications. The use inductive coupling and the sensor tag based on the L-C circuit which senses a parameter by changing its L or C component enable a universal function of the sensor system.

Two different types of antenna were designed and implemented using printed circuit board and handmade wire coil and was found that the handmade planar wire antenna have higher range due to its size. The sensor tag designed as an L-C resonant circuit was designed and fabricated on a printed circuit board with its resonant frequency equal to the frequency of operation. The class E amplifier was designed and then tested as a separate unit using a waveform generator.

A prototype inductive link between the sensor and the antenna was developed and tested to demonstrate the functionality of this new approach. It has been shown that the system can successfully detect wetting of diaper wirelessly through inductive coupling. The difference between the ON and OFF voltage level was first tested for a fixed separation between the antenna and the sensor. The experimental results shows that the operating range of the system is 10 cm, which is sufficient for many household applications like diaper wetting, water leakage, food rotting etc. The sensor tag can be functionalized to achieve wide range of sensing e.g. temperature, humidity, perspiration, toxic gases etc.

Future work can be pursued by making the sensor system capable of achieving level measurement so that it can be used for applications that need level recognition.

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VITA

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